Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

Visualization of Echo Sounder Data with a Micro Computer

R.E. Crawford and J.K. Fox

Central and Arctic Region
Department of Fisheries and Oceans
Winnipeg, Manitoba R3T 2N6

1992

Canadian Technical Report of
Fisheries and Aquatic Sciences
1840

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of

Fisheries and Aquatic Sciences 1840

1992

VISUALIZATION OF ECHO SOUNDER DATA WITH A MICRO COMPUTER

by

R.E. Crawford and J.K. Fox

Central and Arctic Region

Department of Fisheries and Oceans

Winnipeg, Manitoba R3T 2N6

This is the 41st Technical Report

from the Central and Arctic Region

PREFACE

The mention of a brand name product in this report does not constitute endorsement by the authors, Fisheries and Oceans, or the Government of Canada. Other products with similar capabilities can be substituted. SURFER and GRAPHER are registered trademarks of Golden Software Inc., Golden, Colorado. CorelDRAW is a registered trademark of Corel Systems Corporation, Ottawa, Ontario. Freelance Plus is a registered trademark of Lotus Development Corporation, Cambridge, Massachusetts. Epson is a registered trademark of Epson America, Inc. Hewlett-Packard is a registered trademark of Hewlett-Packard Corporation.

(c) Minister of Supply and Services Canada 1992

Cat. no. Fs 97-6/1840E ISSN 0706-6457

Correct citation for this publication is:

Crawford, R.E., and J.K. Fox. 1992. Visualization of echo sounder data with a micro computer. Can. Tech. Rep. Fish. Aquat. Sci. 1840: iv + 17 p.

TABLE OF CONTENTS

	Page
PREFACE	ii
ABSTRACT/RÉSUMÉ	iv
INTRODUCTION	1
DEFINITIONS OF TERMS AND CONCEPTS	1
Echo sounding	1
Visualization	1
COMPONENTS OF AN EXAMPLE VISUALIZATION SYSTEM	1
DATA INPUT REQUIREMENTS	2
Horizontal format	2
Vertical format	2
EDITING ECHO SOUNDER DATA	2
Using visualization during editing	3
THE PROCESS OF VISUALIZATION	3
Visualizing bathymetry or the horizontal distribution of a resource	3
Visualizing the vertical distribution of a resource in the water column	4
Visualizing positional relations	4
ENHANCING VISUALIZED IMAGES	4
REFERENCES	5

LIST OF FIGURES

Figure		Page
1a	Example of visualized raw echo integration data contaminated with echoes of the bottom	11
1b	Same data as Fig. 1a but the unwanted large values have been removed	11
2	Portion of Canadian Hydrographic Service chart 7511 showing Resolute Bay, NWT and features of its shoreline	12
3	A base map generated by the SURFER program, TOPO subroutine, from Fig. 2	12
4	2-D contour plot of bathymetry data collected at 58 m intervals along the survey path shown in Fig. 3	13
5	3-D visualization of the data from Fig. 4	13
6	2-D contour plot of acoustically detected biomass within a pentagonally shaped study area	14
7	3-D visualization (stacked contour plot) of the distribution of fish in a bay	14
8	2-D contour plot of density distribution (fish·m^{-3}) within a fish school	15
9	3-D image of the vertical distribution of water column biomass detected acoustically along a 13.7 km path	15
10a	2-D contour plot of fish distribution (fish·m^{-2}·10 min) near an ice edge in the Canadian Arctic	16
10b	XY-plot of fish density distribution data extracted along the profile line of Fig. 10a	16
10c	Plot of Fig. 10b after exporting to and enhancing with the Freelance program	16
11a	3-D plot of water column biomass along a 3.5 km path	17
11b	Same data as Fig. 11a but the figure has been enhanced with features of the CorelDRAW program	17

LIST OF APPENDICES

Appendix		Page
1	Glossary of terms	5
2	Guide for creating a 2-D contour bathymetric map	5
3	Guide for creating a 3-D plot of bottom contours	6
4	Guide for creating 2-D and 3-D maps of resource distribution	6
5	Guide for creating 2-D topographic cross-sections of fish schools, using contours of fish density or biomass	6
6	Guide for creating 3-D plots of the vertical distribution of biomass within the water column	7
7	Guide to using GRAPHER to examine the profile of a SURFER visualized surface	7
8	Enhancing SURFER and GRAPHER graphical representations with Freelance Plus	7
9	Enhancing SURFER graphical representations with CorelDRAW	8
10	Enhancing SURFER graphical representations with CorelDRAW	9
11	Enhancing the output of GRAPHER Version 1.75 with CorelDRAW	10

ABSTRACT

Crawford, R.E., and J.K. Fox. 1992. Visualization of echo sounder data with a micro computer. Can. Tech. Rep. Fish. Aquat. Sci. 1840: iv + 17 p.

Using computer graphics (visualization) to display various types of sequentially related data, such as that collected with an echo sounder, enhances the presentation, analysis, and interpretation of the data. It also facilitates the data editing process. Several methods are described to execute visualization of hydroacoustic data with a micro computer. Examples of results are presented. General hardware and software requirements are also listed with suggestions for developing a working system. Guidelines for creating publication quality graphical representations of acoustic data are included in appendices.

Key words: graphics; mapping; distribution; fisheries acoustics; echo integration; biomass; abundance; bathymetry.

RÉSUMÉ

Crawford, R.E., and J.K. Fox. 1992. Visualization of echo sounder data with a micro computer. Can. Tech. Rep. Fish. Aquat. Sci. 1840: n + XX p.

L'utilisation de l'infographie (visualisation) pour afficher différents types de données reliées séquentiellement, comme les données recueillies au moyen d'un échosondeur, améliore la présentation, l'analyse et l'interprétation des données. Elle facilite aussi le processus de préparation des données. Plusieurs méthodes de visualisation de données hydroacoustiques au moyen d'un micro-ordinateur sont décrites. Des exemples de résultats sont présentés. Les exigences générales relatives au matériel et au logiciel sont aussi énumérées et des suggestions sont faites en vue de l'élaboration d'un système exploitable. Des lignes directrices pour la création de représentations graphiques de données acoustiques ayant la qualité requise pour fin de publication sont fournies dans les annexes.

Mots-clés: graphique; représentation; distribution; acoustique dans le domaine des pêches; écho-intégration; biomasse; abondance; bathymétrie.

INTRODUCTION

Visualization is a process whereby numerical data are displayed with either 2-dimensional (2-D) or 3-dimensional (3-D) computer graphics. The process results in the compression of large data sets which facilitates data editing, interpretation and presentation. Visualization of acoustic data produces graphical representations which, unlike acoustic echograms, do not demand trained interpretation. Bottom features, such as the edge of a shelf or the contours of a basin, are clearly revealed with these displays. Bathymetric maps of bottom contours can also be easily produced. More specialized uses include depictions of the geographical distribution of fish abundance, or the representation of the vertical distribution of biomass in the water column.

This report is a primer for those who want to incorporate the use of data visualization techniques into their work. It is not a complete instruction manual on the subject. It is only a guide to help users get started with the technique. Although the report is directed to users of fisheries acoustics, visualization of data is not limited to that field. The process has applications to many situations or uses (e.g. display of oceanographic or limnologic data). The examples in the report are presented to illustrate techniques. Full implementation and development of publication-ready graphic images will require elaboration of concepts or processes described.

Visualization of hydroacoustic data is not a novel concept. Workers in this field often employ various graphical techniques to display results of echo integration studies of biomass distribution (see Johannesson and Mitson (1983) for several examples). Also, some manufacturers of acoustic equipment recommend using 3-D graphics to display the depth distribution of detected sound scatterers (see Greene et al. 1988). But in spite of the agreement that graphical visualization techniques are a useful means for displaying results of hydroacoustic studies, data visualization remains a user developed post-processing option.

To facilitate user development of data visualization techniques, this report presents several methods for displaying various types of data collected with an echo sounder. The process is based on the SURFER (version 4.0) micro-computer graphics program (Golden Software, Golden, Colorado). It is assumed that the reader has some familiarity with that and the other computer programs considered. Readers who possess a basic understanding of the principles of echo sounding, will find the section on visualization of bathymetric data applicable to equipment of modest capability. Users of more advanced equipment may find additional ideas for data analysis and representation in the other sections.

This report describes general requirements and procedures for using these methods, and except for the SURFER program attempts to avoid details particular to any one manufacturer's equipment. (Detailed examples specific to particular software are included in several appendices.) The report includes suggestions to facilitate the elaboration of these techniques. The concepts described are germane to the process of visualization of data in general. It is acknowledged that details regarding the use of cited software may change as new products are developed. Sufficient information is included to facilitate the adaptation to other software.

DEFINITIONS OF TERMS AND CONCEPTS

ECHO SOUNDING

As used in this report, the term "echo sounder" refers to any electronic equipment that determines the distance to an underwater target by measuring the time interval between the transmission of pulse of sound and the return of its echo, reflected from the target. This equipment ranges from the simplest devices that are used to measure water depth (a fisherman's "depth finder") to the complex instruments that also determine the numbers and size of targets detected within the water column (echo integrators and target strength analyzers). Descriptions of these various devices are beyond the scope of this paper. Readers are referred to reports such as that by Amos (1980) and Johannesson and Mitson (1983) for background. Definitions of several terms used frequently in this report are included in a glossary (Appendix 1).

VISUALIZATION

Visualization has been defined as a process whereby integrated computing technologies are used to transform the symbolic into the geometric and/or the numerical into the pictorial in order to see the previously unseen (Anon., Digital Equipment Corp., Maynard, MA: Unpublished report). Its purpose is to enhance the speed and efficiency of the data analysis process and to provide new avenues for the perception of insights not previously examined. The potential of data visualization techniques is expanding as new technologies and techniques are being developed. Although there may be similarities between the system described here and those in use elsewhere, this one is supported entirely by micro-computers. As such, it is field-portable, easy to use and relatively inexpensive.

COMPONENTS/REQUIREMENTS OF AN EXAMPLE VISUALIZATION SYSTEM

Although the criteria are many, the specific requirements for a visualization system depend primarily on the objectives behind developing such a system. One consideration is the computer used to run the software. If a user desires to upgrade data analysis capabilities of an acoustic research program which generates a large

amount of acoustic data, the speed and memory-handling advantages of a high speed processor (e.g. 80386 with a math co-processor) will be important considerations. If the application of visualization is less demanding, equipment needs can be downgraded accordingly.

The example visualization system is based on the SURFER graphics program (Golden Software, Inc.). Any similar program will do, but this one was selected because of its ease of use and flexibility regarding input format and export options. It also has several other useful options, such as calculating the area of distribution of a resource. Some of these are elaborated in Appendices 2-6.

The following annotated list describes the hardware and software requirements of an example system adequate for a modest fisheries acoustics research program:

a. Desk top computer (IBM-AT capability or similar) with math co-processor, VGA monitor (minimum), hard disk drive, and extended memory (2 megabytes RAM minimum).
b. Data editing programs (e.g. to delete erroneous records or to convert raw data of an echo integrator into units of fish abundance, density, or biomass).
c. Graphics program (SURFER or similar) for producing contour maps and images with three-dimensional surfaces.
d. Optional graphics program (CorelDRAW or similar), to enhance the output produced by SURFER.
e. Optional data formatting program, for transforming echo sounder output into the input format of the SURFER program.
f. For publication-ready output, a laser printer with postscript capability.

DATA INPUT REQUIREMENTS

Input requirements for the SURFER program dictate that data records be compiled as XYZ triplets. Within a triplet, the X and Y values describe the 2-D location of a data point and the Z value is the datum. Location refers to the coordinates of a grid system drawn on a base map containing the sampling scheme. The origin (X = 0, Y = 0) of the grid system is located in the map's lower left corner. The X dimension (in non-negative values) extends across the page, left to right from the origin; non-negative Y values extend "up" the page. Negative X or Y values extend the axes in the reverse directions. Data locations are typically irregularly spaced, but this is not a requirement. The XY coordinates may also be related to an existing geographic coordinate system (e.g. latitude and longitude). Using the XYZ triplets as data, SURFER creates a new grid (with regularly spaced nodes) by interpolating between the input values. The shape (height) of the interpolated surface of this new grid reflects the dimensions of the data (Z values).

Two formats of mapping will be used for examples of visualizing echo sounder data: horizontal and vertical. Each has its own associated method of data tabulation and is described below.

HORIZONTAL FORMAT

Each record consists of the X and Y coordinates of a map that locate the site where a data point (the Z value) was collected. Typical data are water depths or fish numbers at specific locations within a bay, or a lake. Typical outputs include bathymetric maps or depictions of the geographic distribution of biomass in an area. These maps are frequently oriented in reference to the location of a boundary (e.g. shoreline, study area border, ice edge, etc.). This type of map is also useful for examining echo integration data for evidence of bottom echo or sample-net contamination and for verification of the editing process to remove such contamination (see below).

Examples include:

a. Contour maps of a study area's bathymetry;
b. Contour maps of fish distribution;
c. 3-D representations of bottom depth contours;
d. 3-D representations of the horizontal distribution of echo integrated biomass within a specified area (e.g. lake, bay, study area).

VERTICAL FORMAT

The X-dimension of the array corresponds to units of distance travelled by a boat and the Y-dimension corresponds to the depth in the water beneath the vessel. The Z values may be depth of the bottom or depth-stratified abundance or biomass data obtained from the water column.

Examples include:

a. Cross-sections (contour representations) of fish schools displaying density distribution within schools;
b. 3-D representations of the vertical distribution of echo integrated biomass beneath a survey vessel.

EDITING ECHO SOUNDER DATA

Data editing requirements will vary, depending on the ultimate objective of the data analysis. For those visualizing bathymetric data, the amount of editing may be modest. However, if visualization is being used to

"clean up" a data set prior to the estimation of abundance or the mapping of a resource's distribution, the data editing process may be much more involved.

For example, to visualize bathymetric data, only the distance to the bottom and the location of the measurement are required. This information can be obtained with the simplest equipment. Most elementary acoustic "bottom finders" do not store data but rather present it in a continuously updated visual display. Users of this equipment are required to tabulate sequential measurements of bottom depth in relation to vessel position, so that records of depth can be transferred to a grid describing the vessel track.

To register accurate depth measurements, several data editing tasks need to be considered: 1) false bottom echoes generated from dense fish schools must be deleted, 2) depth values may have to be corrected to include the depth of the submerged transducer, and 3) depth values may also have to be converted to negative numbers in order to achieve appropriate pictorial representation (otherwise a 3-D image of bottom topography will have elevated contours rather than depressed ones).

These tasks are made easier with equipment that produces a permanent echogram recording. Bottom depth is continuously tracked by the equipment. The user's task is simplified to maintaining a record of vessel position in relation to data recorded on the echogram. More advanced equipment does many of these tasks automatically and stores the information on a medium that can be accessed by computer. However, the complexity and costs of integrating acoustic data acquisition systems with navigation systems can be considerable. For visualizing bathymetric data their main advantage may lie in the ease at which data can be stored and retrieved. For less demanding studies, a modest acoustic device may suffice.

If complex equipment like an echo integrator is used to estimate resource abundance or density, data visualization may have broad editing requirements. Examples of these possible editing tasks are:

a. Evaluating bottom tracking fidelity to avoid bottom echo contamination;
b. Removing sampling net contamination;
c. Deleting data contaminated with transducer tow cable strumming noise;
d. Removing ship's machinery and propeller noise contamination;
e. Cancelling hydroacoustic system non-reverbatory noise;
f. Adjusting for biological/oceanographic phenomena;
g. Incorporating transducer depth adjustment;
h. Selecting subsets of data (by depth range or by contiguous or non-contiguous record numbers);
i. Filtering data with either a minimum or maximum "threshold" value;
j. Changing depth values in depth stratified output from strata endpoints to midpoints.

USING VISUALIZATION DURING EDITING

Some editing procedures incorporate data visualization themselves. For example, successful echo integration is dependant upon the elimination of all traces of bottom echoes. Tracking the bottom so it can be properly eliminated is either an automatic function of a modern echo integrator, or else it is executed manually, a process demanding accomplished skill and dexterity. Neither process is precise and bottom echo contamination is common.

The fidelity of the bottom tracking process can be evaluated by displaying a 3-D representation of the data (in vertical format) in order of transmission number (X-axis) and depth (Y-axis). The visualized data are compared with the echogram obtained during the data collection procedure. Anomalies at the seabed, particularly those which dominate in terms of the scale of the Z-axis, frequently indicate bottom echo intrusion (Fig. 1a). The offending data cell(s) can be identified with the help of the 3-D image and can be either deleted or "corrected" (Fig. 1b), depending on the justification criteria.

For example, if the goal is to create an image representing the vertical distribution of biomass in the water column, then the value in the offending cell(s) may be changed to an interpolated value appropriately referenced to values in neighbouring cells. If the goal is to check data prior to the derivation of a numerical estimate of biomass, the offending cell may be deleted altogether. Other sources of data contamination, such as transducer tow cable strumming noise, are identified and processed in a similar manner.

THE PROCESS OF VISUALIZATION

VISUALIZING BATHYMETRY OR THE HORIZONTAL DISTRIBUTION OF A RESOURCE

The capability to create depictions of bathymetric features has proven to be extremely useful in the Arctic where bathymetric information on hydrographic charts is often sparse. It has also proven to be useful in better surveyed waters in more southern latitudes when 3-D representations can reveal relationships and shapes not as easily interpreted from bathymetric charts.

The horizontal format of data compilation is required to create a 2-D or 3-D horizontally oriented map. The path of the survey vessel's cruise track followed during the data collection process (often referred to as a

transect) is superimposed onto a base map of the survey area. The base map contains geographic or boundary information (Fig. 2) useful for referencing the mapped data values. Because of the large number of samples taken during a typical acoustic study, echo sounder data are usually grouped into "sequences" containing a discrete number of echo sounder transmissions ("pings"). Sequence length is translated into a unit of distance along the transect.

Each transect is divided into the number of sequences it contains. The XY coordinates of each sequence are identified according to a grid system placed on the map. Variables (Z values) such as depth, fish density (numbers per unit area) or fish biomass (weight per unit area) are assigned to their respective location (XY coordinates). The coordinates of the shoreline and other pertinent features are also compiled.

Depth data may represent the depth at the last ping of the sequence or its mean depth, depending on the capability of the data storage system. Biomass and other variables are usually the total value for each sequence. If a Z value is derived from the total or end-point of a sequence, then the coordinates of that location is recorded. If the data represent a mean value, the X and Y coordinates of the mid-point location for each sequence are recorded instead.

The XY coordinates of the shoreline features and the XYZ triplets for the data values are imported to the SURFER program and either 2-D or 3-D graphical representations of the bottom contours can be depicted (Fig. 3-7). See Appendices 2-4 for detailed examples of this process.

VISUALIZING THE VERTICAL DISTRIBUTION OF A RESOURCE IN THE WATER COLUMN

The vertical format of data compilation is required to create a 2-D or 3-D vertically oriented map. Depth-stratified echo sounder data are grouped into sequences containing a fixed number of sounder transmissions or "pings". Data are sorted into cells by sequence number and depth. The deepest cell of the first sequence is nearest the origin of the mapping coordinate system. Data within the appropriate sequences and depth ranges which contain the area of interest are selected.

The SURFER program locates the XYZ origins in a graphic representation at the lower left corner. Interpolated surfaces are projected "upward" from the origin. To keep the perspective of visualized acoustic data properly oriented to the surface of the water (i.e. depth axis projected "downward"), depth values (X values) are multiplied by -1 to place the water's surface at the top of the graphical output. Also, the order of sequences (Y values) in alternate transects may be inverted to properly orient the display of a group of transects that repetitively altered direction (e.g. followed a zig-zag or parallel course). Other data editing may also be required, as described previously. Edited data are then exported to the SURFER program for visualization (Fig. 8, 9). See Appendices 5 and 6 for specific examples.

VISUALIZING POSITIONAL RELATIONS

The contour plots and 3-D images described above are maps that display a large amount of information about an area or a resource. SURFER has a useful option which allows examination of the relation among elements contained within these maps. A visualization is created with either the horizontal or vertical format. A profile line which connects (or passes through) the objects of interest is drawn on the visualization (Fig. 10a). The XY coordinates of the profile line are obtained by superimposing the line onto the base map containing the coordinate system for the visualization. These values are input to the SLICE subroutine of SURFER. It creates an ASCII file which contains information describing XYZ values of the profile and accumulated horizontal distance along the profile line.

This file is exported to another program (e.g. GRAPHER program; Golden Software, Golden, Colorado) where the profile can be plotted as an XY-graph (Fig. 10b). The X-axis represents the distance along the line and the Y-axis is the height of the visualized surface (interpolated from Z values). Such plots augment the examination of the distance between mapped contours (Fig. 10c) and facilitate the comparison of different areas of a figure's surface. See Appendices 7 and 8 for detailed examples.

ENHANCING VISUALIZED IMAGES

Although SURFER has adequate capability for producing high quality representations, a user may have custom requirements that this program cannot fulfil. For example, land features on maps are more readily discernable when they are shaded (Fig. 6). Likewise, shading can enhance the interpretation of contour map gradients in abundance or density distribution (Fig. 8). It may also be desirable to add information to a SURFER graphic (Fig. 11). In these cases, the SURFER figure can be exported to a full screen graphic program (e.g. Freelance Plus or CorelDRAW) for enhancement. Refer to Appendices 8-11 for details regarding this technique.

SURFER (and most enhancement programs) has drivers for graphic pen plotters. This allows for the addition of colour to visualizations. This report is limited to the discussion of black-and-white images suitable for ordinary publication purposes. Users who want to include colour in their graphic images will find instructions in the program documentation.

REFERENCES

AMOS, D. 1980. A fisherman's guide to echo sounding and sonar equipment: acoustic fish detection instruments. University of Rhode Island Marine Bulletin 41. 67 p.

GREENE, C.H., P.H. WIEBE, J. BURCZYNSKI, and M.J. YOUNGBLUTH. 1988. Acoustical detection of high-density demersal krill layers in the submarine canyons off Georges Bank. Science 241: 359-361.

JOHANNESSON, K.A., and R.B. MITSON. 1983. Fisheries acoustics. A practical manual for aquatic biomass estimation. FAO Fish. Tech. Pap. 240: 249 p.

APPENDICES

APPENDIX 1. GLOSSARY OF TERMS.

Biomass: A measure of the quantity of living material, usually in units of weight per unit volume.

Density: The amount of organisms in a unit volume, usually as abundance (numbers·m^{-3}) or biomass (kg·m^{-3}).

Echogram: A form of display used to present acoustic data from an echo sounder. Originally created by a strip paper chart recorder. Modern versions present the same kind of display electronically, as on a computer display.

Echo integration: The process of summing acoustic echo intensities over a time interval to estimate echo energy. This latter quantity is related the amount of biomass or abundance of organisms in the water column.

Echo sounder: An acoustic system which transmits short acoustic pulses into the water (usually vertically) and detects echoes from the bottom or from organisms in the water column.

Ping: An acoustic pulse transmitted into the water column by an acoustic system.

Surface density: The amount of organisms in a unit area, usually as abundance (numbers·m^{-2}) or biomass (kg·m^{-2}).

Target: As used in this report, a sound scatterer detected in the water column.

Target strength: A measure of the reflectivity of an acoustically detected sound scatterer.

Transducer: A device used to convert electrical energy to acoustic energy (when transmitting sound) or vice versa (when receiving or "listening for" echoes).

APPENDIX 2. GUIDE FOR CREATING A 2-D CONTOUR BATHYMETRIC MAP.

Note: Appendix 2 refers to Fig. 2-4.

1. For this example, a base map was created by tracing the outline of Resolute Bay, Cornwallis Island (Northwest Territories) from chart 7511 of the Canadian Hydrographic Service onto graph paper. The base map outlined the coastline, rivers, and islands. The map was oriented on the graph paper so that the horizontal and vertical lines of the graph paper would comprise elements of a coordinate system with its origin at the lower left corner of the base map.

2. The survey path followed by a research vessel during an echo sounding survey of the bay was also plotted on the map (Fig. 2).

3. The outline of shoreline features and the survey path were input into SURFER as a boundary line file (extension = .BLN). This file consisted of a list of XY coordinates of the shoreline, the course of two rivers which enter the bay, and the survey track, as read from the graph paper in step 1. (A .BLN file has no Z values.) A TOPO subroutine plot of the .BLN file (Fig. 3) indicates the coverage of the grid compiled from the input coordinates.

4. The plotted survey path (transect) was divided into legs. Each leg defined a single direction in which the boat cruised to obtain data. The legs were segmented according to the number of sequences (groups of pings transmitted by the echo sounder) that were recorded during each leg. The XY coordinates of the end of each sequence were listed. The depth values (Z values) for the last ping of each sequence, as recorded by an echo integrator, were compiled with their respective X and Y coordinates into respective XYZ triplets. The sign of the depth values was changed (Z multiplied by -1) to reference the interpolation to depths below sea level (i.e. the visualized surface was depressed rather than elevated).

   An ASCII file of the list of triplets was prepared as a SURFER data file (.DAT extension). Concatenated to this file was of a copy of the shoreline portion of the .BLN file (XY values) which had been altered with the addition of a third column (Z values) of zeros. This last step was required to locate data values of zero at the shoreline, so that the SURFER interpolation algorithm would start at the appropriate level for that location.

5. The .DAT file was then converted by SURFER to create a grid file. Because in this case there was a relatively large portion of the survey area without data, the inverse distance method of interpolation was selected. Otherwise, kriging would have been the choice. Standard defaults of the program were used with the exception of the following:

   a) 30 X 30 grid size to help reduce the block-like appearance of the default 25 X 25 grid.

b) Duplicate points were averaged.

6. The grid file was manipulated (cubic spline smoothing method with expansion set at 2) to create a smoother appearance without losing relief. This action produced an 88 X 88 grid.

7. The grid file was input to the TOPO routine of SURFER and a contour plot of the bathymetry data was created.

8. The final output (Fig. 4) was derived from editing SURFER's grid in the Grid Edit mode of the TOPO routine. The relatively small grid search radius of nine data units resulted in an undesired interruption in the surface of the land mass area on the east (right-hand) side of the figure. This interruption was similar to that depicted in the foreground portion of Fig. 4 and 5. Both breaks in the plotted surface occurred in portions of the figure that exceeded the search radius distance to the nearest data points. The interruption of the east side was eliminated by inserting data values of 0 into the affected area (a land mass that was not part of the bathymetric data set). The interruption in the foreground, where bathymetric data were lacking, was blanked from Fig. 4.

APPENDIX 3. GUIDE FOR CREATING A 3-D PLOT OF BOTTOM CONTOURS.

Note: Appendix 3 refers to Fig. 4 and Fig. 5.

This type of map (Fig. 5) is created in the same manner as a 2-D map except the grid created in SURFER (as described in Appendix 2.) is routed to the SURF function rather than the TOPO function. For Fig. 5, standard SURF defaults were used to create the image with the following exceptions:

a) The search radius for the grid was set to 9 data units. (This had the effect of opening up the mouth of the bay. With the default setting, this region was blocked from view.)
b) View is from 280 degrees at 20 degrees of tilt in order to maximize the area of the bay visible to the observer, and to emphasize relief.
c) Maximum Z value was changed from 0 to -1 to reduce the amount of "extraneous" interpolation in the areas of the land mass surfaces.
d) A base for the plot was selected to give a better appreciation of relief.
e) Z scale factor was set to 0.15 to emphasize relief variations.

[Note: The examples depicted in Appendices 2 and 3 represent a good demonstration of the visualization data entry process. They also reveal how much information can be derived from relatively few data points. The data for the map were obtained from only six crossings of the bay while recording the depths at 30 s intervals (boat speed = 7 $km \cdot h^{-1}$). Although data for the depiction were gathered with an echo integrator that automatically records depth information, similar results could have been obtained from manually tabulated depths measured with an inexpensive echo sounder. Comparison of the visualized maps (Fig. 4 and 5) with chart 7511 (Fig. 2) indicates agreement in many locations.]

APPENDIX 4. GUIDE FOR CREATING 2-D AND 3-D MAPS OF RESOURCE DISTRIBUTION.

Note: Appendix 4 refers to Fig. 6 and Fig. 7.

These maps (Fig. 6 and 7) are made in the horizontal format in a manner similar to that used for a bathymetry map except that Z values are biomass or abundance data expressed in terms of volume or surface area (e.g. mean numbers$\cdot m^{-2}$). These data are the totals for the sampled portion of the water column within each sequence. Data file triplets consist of sequence mid-point location (X,Y values) and biomass or numbers per unit area (Z values).

[Note: By convention of fisheries acoustics methodology, when relating biomass or abundance to the size of a study area, data obtained from a closed body of water (e.g. a lake) are usually expressed in volumetric terms ($\cdot m^{-3}$). With data from an open body of water, such as a survey of the marine environment, units of surface area ($\cdot m^{-2}$) are used (Johannesson and Mitson 1983).]

See also Appendix 7.

APPENDIX 5. GUIDE FOR CREATING 2-D TOPOGRAPHIC CROSS-SECTIONS OF FISH SCHOOLS, USING CONTOURS OF FISH DENSITY OR BIOMASS.

Note: Appendix 5 refers to Fig. 8.

This method uses the vertical format and requires data expressing biomass or numbers of individuals per unit volume (e.g. $kg \cdot m^{-3}$). This type of visualization is usually restricted to data within a transect where a concentration of fish was detected. The following example illustrates this process.

1. Echo integration data are depth-stratified into narrow depth ranges (e.g. 1-2 m) and then sorted by sequence number and depth.

2. Depth values are multiplied by -1 to locate the water's surface (depth = 0) at the top of the figure.

3. If areas within two adjacent transects within a survey are being visualized, it may be necessary to reverse the order of sequences in one of them to maintain proper orientation within the two figures. For

example, the visualization process is executed with the origin in the lower left corner. We want to visualize data collected during two transects, one crossing a bay in one direction and the next, returning in the opposite direction. If data for the first transect were collected from a boat travelling west to east, the left side of the figure would be toward the west, proper orientation. But to create a properly oriented figure from the following transect that began on the east side, sequence order must be reversed.

4. Additional editing tasks, such as adjustment for transducer depth, may also be required.

5. Data are compiled into a SURFER data file as follows: X value = sequence number, Y value = mid-point of stratum depth range, and Z value = derived density or biomass estimate for that depth interval of that sequence.

6. Triplets for the location of the sea bed for each sequence (X value = sequence number, Y value = bottom depth at the last ping of each sequence, Z value = zero) are concatenated to the data file.

7. The data file is input to the GRID program. Due to the high density of data points within the area of interest, the kriging method of interpolation is chosen. Default parameters are often satisfactory.

8. Optionally, a boundary file of bottom depths for each sequence can also be complied from the X Y values used for item 6. This file is used for plotting a line that depicts the bottom contour beneath the concentration of fish.

9. The grid created as output of the GRID program is smoothed (cubic spline method, expansion = 2) and then exported to the TOPO program for plotting as a contour plot of biomass distribution. Default parameters are satisfactory for the initial examination of the visualized results.

10. Final versions (Fig. 8) can be optimized by making appropriate adjustments (axes, labels, etc.) or by exporting the figure to an enhancing program (see below).

APPENDIX 6. GUIDE FOR CREATING 3-D PLOTS OF THE VERTICAL DISTRIBUTION OF BIOMASS WITHIN THE WATER COLUMN.

Note: Appendix 6 refers to Fig. 8 and Fig. 9.

This type of plot (Fig. 9) is created in the same manner as those for Appendix 5 (Fig. 8), except the smoothed SURFER grid is routed to the SURF program for the creation of a 3-D plot. The .BLN file of the bottom contour can be plotted as an X-Y line, a task benefitting from the use of an enhancement program (see below) where the thickness of the line can be increased for it to be readily seen.

See Appendix 7.

APPENDIX 7. GUIDE TO USING GRAPHER (VERSION 1.75) TO EXAMINE THE PROFILE OF A SURFER VISUALIZED SURFACE.

Note: Appendix 7 refers to Fig. 10a and Fig. 10b.

1. A 2-D or 3-D visualization is created with either the horizontal or vertical format. The grid is routed to the TOPO routine in SURFER and the image is displayed in the 2-D form (Fig. 10a).

2. A profile line which connects (or passes through) the objects of interest is located on the image (Fig. 10a). The XY coordinates of this line are obtained by superimposing the line onto the base map containing the coordinate system for the visualization.

3. These values are input to the SLICE subroutine in SURFER. It creates a .DAT file that contains information describing XYZ values along the profile, as well as accumulated horizontal distance along the line.

4. The .DAT file is exported to GRAPHER where an XY-graph is created (Fig. 10b). The variable assigned to the X-axis is the cumulative distance along the profile line in data units. The variable for the Y-axis is the Z datum.

APPENDIX 8. ENHANCING SURFER AND GRAPHER GRAPHICAL REPRESENTATIONS WITH FREELANCE PLUS (VERSION 3.01).

Note 1: Appendix 8 refers to Fig. 10c.

Note 2: For Appendices 8-11, comments apply to experiences learned with ink jet and laser printers with a maximum resolution of 300 dots per inch (dpi). Results with other equipment may differ.

1. Freelance Plus version 3.01 has a 40K worksheet space. Drawings or graphs that exceed 40K cannot be imported. This limits "enhancement" to only simple diagrams.

2. When a graphic is imported as a SURFER .PIC file, the right side of the diagram is often cut-off. Modifying the scaling dimensions of the diagram does not help on a consistent basis. To retain the right side of the diagram when importing a .PIC file, modify the .BLN file by inputting a small line to the right of the normal boundary. If the line extends 4-5

units further than the normal boundary, the graphic usually imports completely. The extra line can be deleted with the Freelance Plus edit function. Scaling the SURFER diagram to about 14 cm (5-6 inches) gives consistent results.

3. Images frequently distort (compress vertically) when imported into Freelance Plus. (This occurs even when there is no line segment to the right of the normal boundary in the .BLN file.) A solution is to choose "select all" from the edit menu. Then stretch the diagram vertically until the proportions of the diagram match those of the graph paper plot, base map, or regular surfer plot.

4. Freelance Plus is less complicated (and is therefore easier or faster to learn) than CorelDRAW (described below) but does not have as many features. It is better adapted for creating or enhancing graphs (Fig. 10c). Because of its limitations, serious users of visualization are advised to use a more capable program such as CorelDRAW.

APPENDIX 9. ENHANCING SURFER GRAPHICAL REPRESENTATIONS WITH CORELDRAW VERSION 1.1.

1. CorelDRAW 1.1 is limited by its use of RAM and the way in which it "reads" a diagram into a worksheet. Splined 3-D grids created by SURFER are segmented into thousands of tiny objects that comprise the whole picture. Because each segment is considered a separate object by CorelDRAW, memory capacity can be very quickly exceeded. 2-D contour images (and some 3-D images with "constant Z values") require much less memory and can be imported with little difficulty in this regard. (Improvements to version 2.0 of this program have rectified this problem; see Appendix 10.).

2. When a graphic is imported into CorelDRAW 1.1 as a SURFER .PIC file, the right side of the diagram may be cut-off. Modifying the scaling dimensions of the diagram did not help on a consistent basis. The best way to retain the right side of the diagram when importing is to modify the .BLN file by inputting a small line to the right of the normal boundary. If the line extends 4-5 data units further than the normal boundary, the graphic usually imports completely. To ensure success, scaling the SURFER diagram to about 15 cm (5-6 inches) gives consistent results.

3. Graphic images frequently distort (compress vertically) when imported into CorelDRAW. (This occurs even when there is no line segment to the right of the normal boundary in the .BLN file.) This can be corrected by deleting the extra line segment created in the .BLN file, after importing the graphic, and then choosing "select all" from the edit menu. Then stretch the diagram vertically until its proportions have been corrected. The "Transform - stretch and mirror" menu can be used, but it is faster to simply drag the image to the correct size with the mouse using the program's "rulers" as a guide.

4. If you desire to import a SURFER graphic with the locations of the data (Z) values identified ("posting"), use the default symbol (#49) to flag the data points. Do NOT attempt to import a more-complex symbol (such as CENTRED.SYM #69 - a circle). CorelDRAW reads each symbol as many individual line segments, a process that uses a lot of memory. The symbol can be changed after importing using the CorelDRAW editor.

5. If you do not need postings on the CorelDRAW image, it is best to eliminate them in SURFER prior to creating an export file. This will free-up memory in CorelDRAW. If you do import the postings and desire to delete them or perform other "group operations" on them, it is best to do it prior to "deselecting" them because these symbols are automatically grouped by CorelDRAW during importation. This will save you the task of having to re-select and re-group all of the posting symbols at a later date if you have a need to manipulate them. This can be a very tedious process since each posting symbol is comprised of more than one object.

6. When importing to CorelDRAW, avoid labelling contour lines in SURFER. Because text is imported as curve segments, it cannot be manipulated as text. This is also important if you wish to perform "fills" within contour lines. The SURFER contour labels will leave a break in the contour lines and thus not allow a proper "fill" operation to take place until all the breaks are joined together (a multi-step operation). Enhancing contour labels in CorelDRAW can be done easily if you use SURFER to print a separate plot with contour labels. Use this as a reference for labelling the lines in CorelDRAW with its text editor.

7. Do not combine images or areas with differences in "fill" patterns or other characteristics. The "combined" areas will take on the characteristics of the first object selected and the differences will be lost from the file. (Once combined, you cannot "break apart" the combined objects to restore the original image.) Combining areas with the same line weights, fills, etc. is a great way to save memory, however, and should be utilized when possible. It also decreases "re-draw" time immensely, especially when using the Preview window with more complex drawings.

8. If a user desires to print a graphic with Postscript fills or text, use the default resolution (60 dpi) for all of them during the manipulation of the graphic in CorelDRAW (adding text, labels, changing line weights, etc.). After all modifications are executed, the default "fill" resolution can be changed to the desired density. If resolution is increased, the number of visibly different tone levels is reduced. If the resolution is decreased, the tones become more granular in appearance. Seventy dpi work well for images being reproduced at or near 100% scale. Sixty dpi are better for images being moderately reduced.

APPENDIX 10. ENHANCING SURFER GRAPHICAL REPRESENTATIONS WITH CORELDRAW VERSION 2.0.

Note: Appendix 10 refers to Fig. 11a and Fig. 11b.

1. Large files, such as splined 3-D surfaces from SURF, can be imported into CorelDRAW version 2.0 using the HPGL file format (Hewlett-Packard Graphics Language File). To create an HPGL file for export from Surfer, select the HP Graphics Language File (43) from the Environment Plot Dev menu in Surf and send the output to a file. (If that driver is unavailable, select an HP7475A plotter as an output device.)

   In CorelDRAW, select HPGL from the Import File Format menu. Hit <enter> and go to the directory where your HPGL SURFER file is. In the CorelDRAW "path" statement box, change the extension from ".PLT" to ".PGL" so that all HPGL files in the directory appear in the "Files" box. Select the desired .PGL file and the import process should begin when you hit <enter> again. (If you intend to perform this type of importation frequently, the default settings for the file extension can be changed from .PLT to .PGL.)

2. Smaller files can be imported as Lotus .PIC files. The .PIC format is much easier to work with in the CorelDRAW editor, because the .PGL file "combines" portions of the image to save memory as it imports. HPGL format should not be used to import contour maps unless it is required due to the large size of a file.

3. The same rules apply to .PGL files as explained for .PIC files (Appendix 9) with respect to removing text, contour labels, and use of posting marks.

4. Distortion (vertical compression) of the image occurs when importing .PGL or .PIC files, and appropriate re-scaling will be necessary as for version 1.1.

5. Unlike version 1.1, CorelDRAW 2.0 does not cut-off the right side of the imported image if it was scaled to less than 20 cm (8 in) in SURFER prior to creation of the export file. It doesn't matter which menu option is selected to scale the image (Scale, Output-scale, PLOT-scale image) as long as the plot is scaled and positioned to be completely within the bounds of a letter-size page. Fifteen centimetres (6 in) is a good size for TOPO maps, and 10-15 cm (4-6 in) works well with SURF figures, depending on the view angle. These same restraints apply when exporting a file from CorelDRAW. The key is to work with an image that fits within the boundaries of a standard letter-size page.

6. The following notes pertain to the process of editing CorelDRAW files imported using the HPGL format:

   a) Delete grid lines on land surfaces or other extraneous areas using the node edit tool. Reducing the number of unnecessary line segments will save memory, increase speed, and alleviate some potential problems when completing further editing.

Note: When manipulating many nodes or a complex object, or when switching between the "node edit" and the "select tool" modes, it is best to be "zoomed out" so the drawing is small on the screen. This reduces screen re-drawn time noticeably.

   b) Outlined areas of the SURF base or map borders should be traced with the pencil (draw) tool prior to the deletion of grid lines. The map borders are often incorporated as combined objects and will therefore be erased when deleting nodes unless they have been traced.

   c) Once all unnecessary grid segments have been eliminated, it may be possible to "break-apart" the remaining sections without causing memory problems. You should not do this unless it is necessary for editing.

   d) To save memory and decrease screen "redraw" time immensely during editing, leave areas that were combined initially in their "combined" format. When finished editing sections that have been broken apart, combine as much of the surface as practical. Most parts of the gridded surface have been combined with the maximum number of nodes (about 4000) already, so you may not be able to re-combine larger parts of the grid to further save memory.

APPENDIX 11. ENHANCING THE OUTPUT OF GRAPHER VERSION 1.75 WITH CORELDRAW VERSIONS 1.1 AND 2.0.

1. When importing GRAPHER files into CorelDRAW, use the .PIC file format, rather than the "Rel 9 .DXF" option because it is easier to work with the

.PIC files. Scale and position the graphs using the same rules that apply to SURFER files, above.

2. Ensure that tic mark spacing on the axes is adjusted in GRAPHER prior to creating the export file. This is not mandatory, but it is far easier to complete the graph with the tic marks already in the desired positions. Whether to import labelled tic marks depends on the desired output. When axes labels (numbers) are imported, the tic marks adjacent to them are slightly longer than the non-labelled tic marks. Unlabelled axes have tic marks of equal length.

3. Remove any Grapher-created titles, etc. prior to importing if memory or speed is a concern. Since most graphs are very small this should not be necessary. Text can be easily replaced with the CorelDRAW editor.

See also Appendix 8.

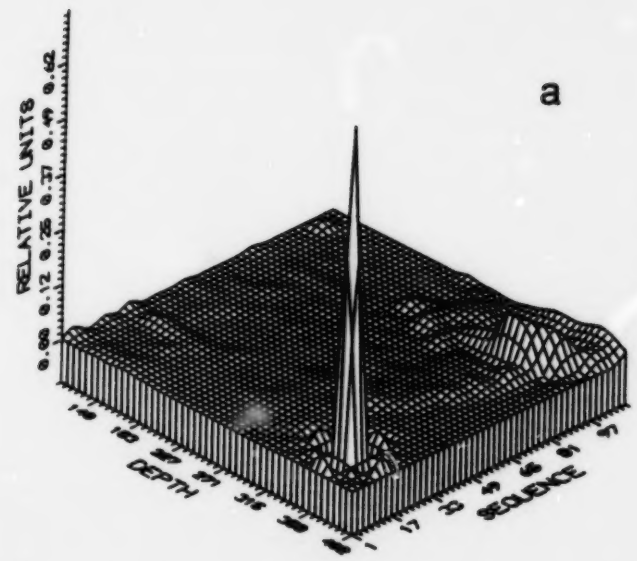

Fig. 1a. Example of visualized raw echo integration data contaminated with echoes of the bottom. Note how one spike (representing data values exceptionally larger than the rest) dominates the scale of the Z-axis.

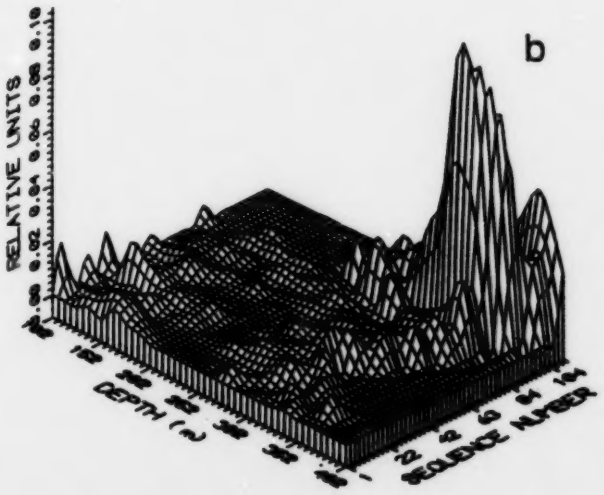

Fig. 1b. Same data as Fig. 1a but the unwanted large values have been removed. Note the change in the scale of the Z-axis compared with Fig. 1a.

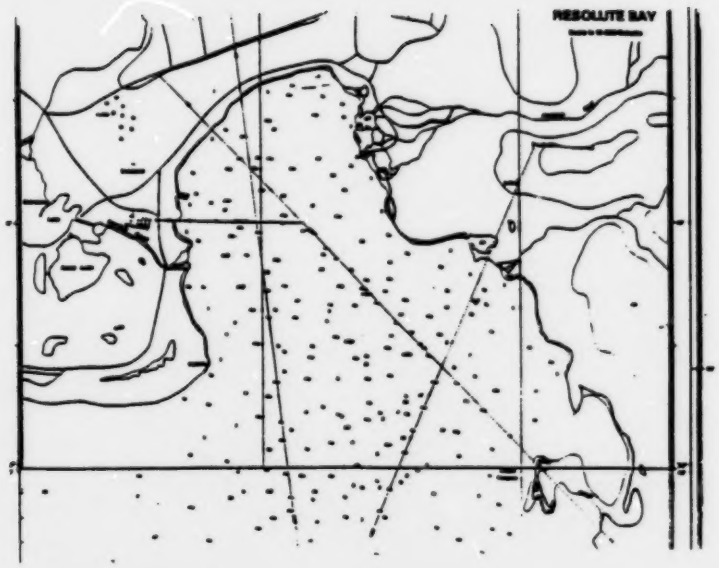

Fig. 2. Portion of Canadian Hydrographic Service chart 7511 showing Resolute Bay, NWT and features of its shoreline.

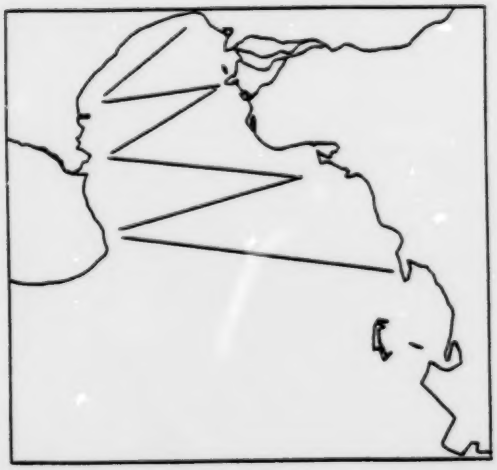

Fig. 3. A base map generated by the SURFER program, TOPO subroutine, from Fig. 2. The base map is a 2-D representation of the XY coordinates of the shoreline, major river beds, and the zig-zag cruise track of a research vessel.

Fig. 4. 2-D contour plot of bathymetry data collected at 58 m intervals along the survey path shown in Fig. 3 (SURFER program, TOPO subroutine).

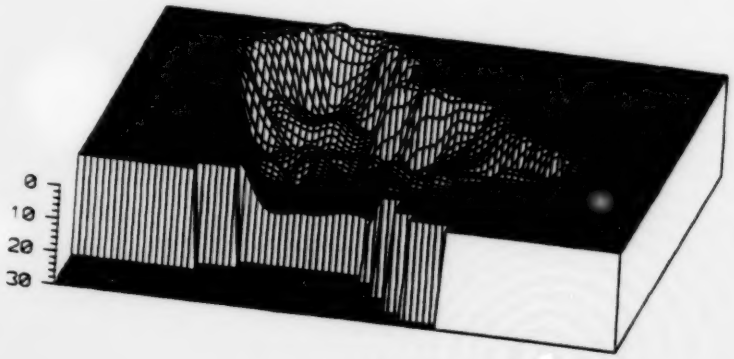

Fig. 5. 3-D visualization of the data from Fig. 4 (SURFER program, SURF subroutine).

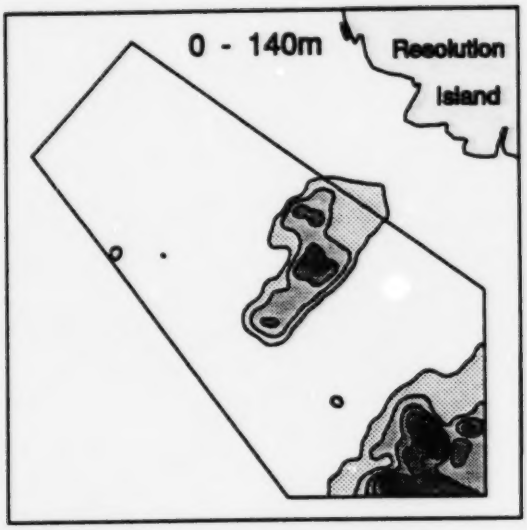

Fig. 6. 2-D contour plot of acoustically detected biomass within a pentagonally shaped study area (SURFER program, TOPO subroutine). Shading and text were executed with CorelDraw.

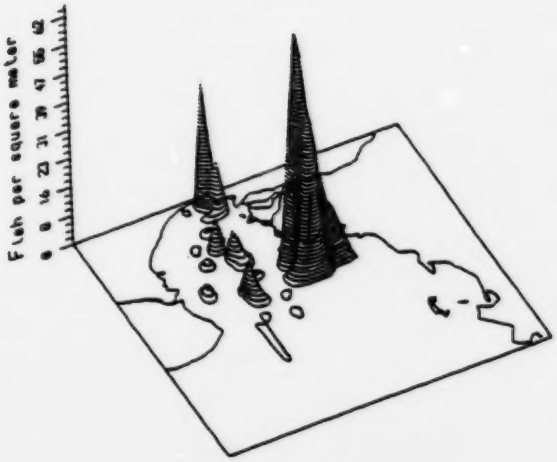

Fig. 7. 3-D visualization (stacked contour plot) of the distribution of fish in a bay (SURFER program, SURF subroutine).

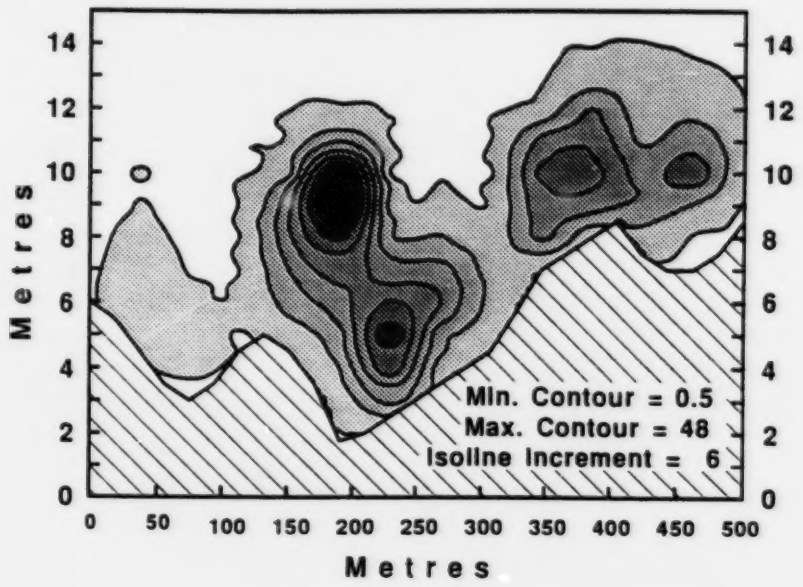

Fig. 8. 2-D contour plot of density distribution (fish·m^{-3}) within a fish school (SURFER program, TOPO subroutine). Shading and labelling executed with the CorelDRAW program.

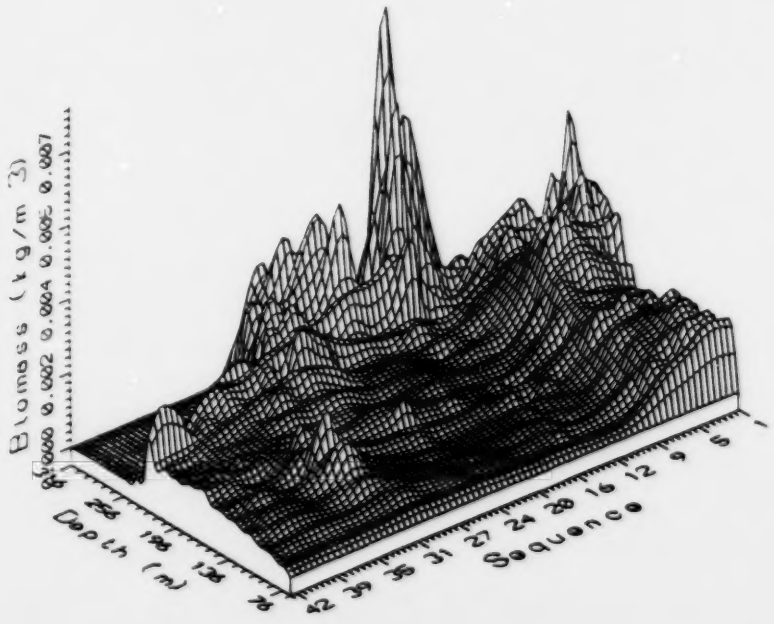

Fig. 9. 3-D image of the vertical distribution of water column biomass detected acoustically along a 13.7 km path (SURFER program, SURF subroutine).

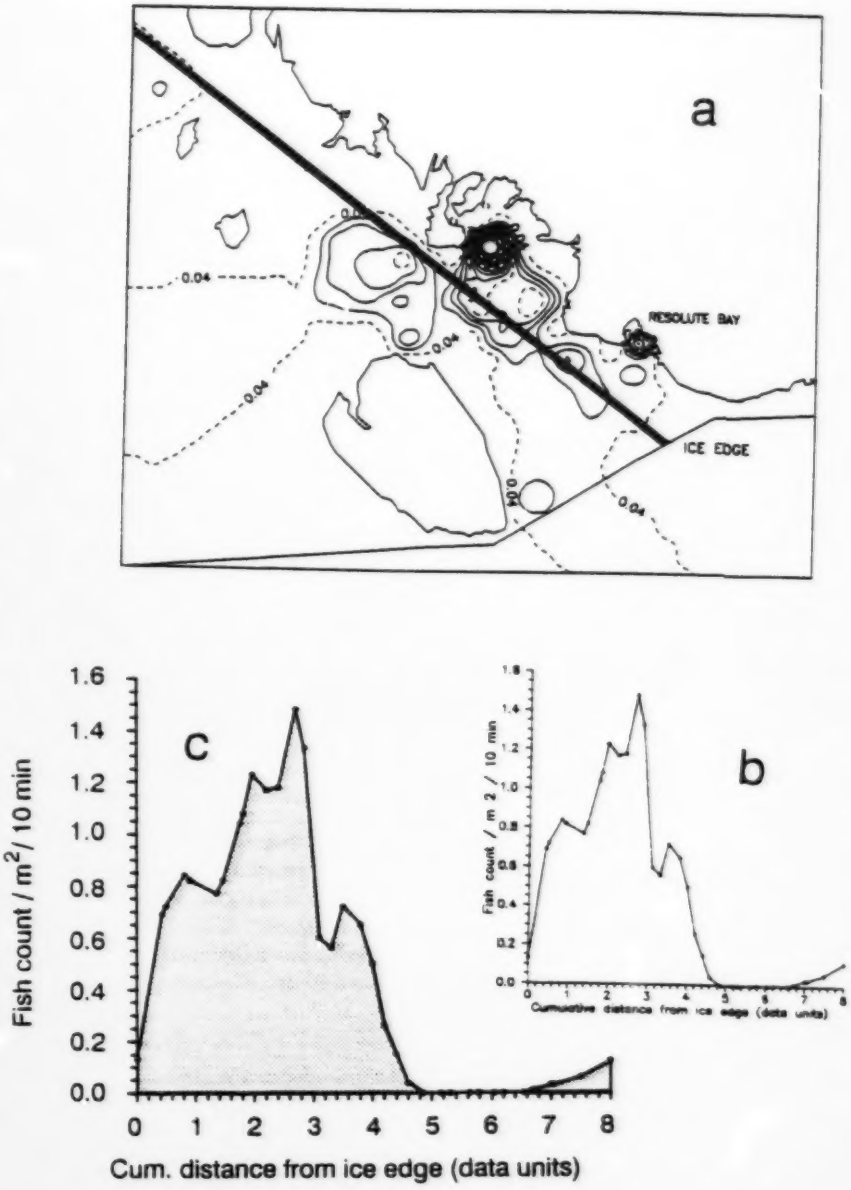

Fig. 10a. 2-D contour plot of fish distribution (fish•m^{-2}•10 min) near an ice edge in the Canadian Arctic (SURFER program, TOPO subroutine). Diagonal line indicates location of profile information extracted by the SLICE subroutine of SURFER.

Fig. 10b. XY-plot of fish density distribution data extracted along the profile line of Fig. 10a (GRAPHER program).

Fig. 10c. Plot of Fig. 10b after exporting to and enhancing with the Freelance program.

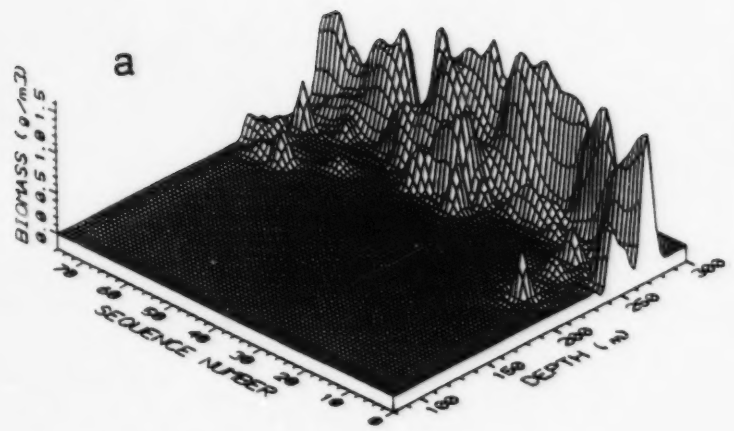

Fig. 11a. 3-D plot of water column biomass along a 3.5 km path (SURFER program, SURF subroutine).

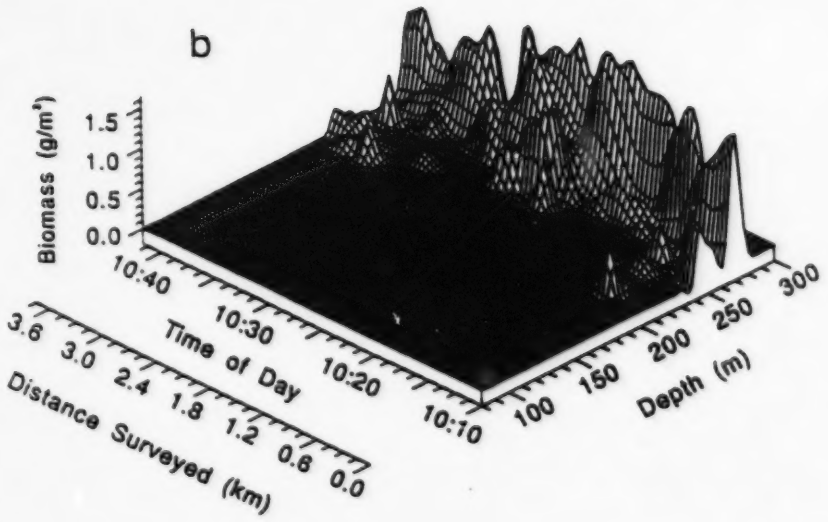

Fig. 11b. Same data as Fig. 11a but the figure has been enhanced with features of the CorelDRAW program.